Tallapoosa River, Alabama

Chapter 7: Integrating the Components of Adaptive Management

In previous chapters we discussed the elements and processes of adaptive management as we define them in this guide, and illustrated them with examples from the thematic areas of climate change, water resources, energy development, and human impacts on the natural landscape. We treated the components of adaptive management separately in individual chapter sections in order to highlight the common features of each component among the themes.

In this chapter we show how these components are integrated in the application of adaptive management in the field. Our examples include management of river flows, management of breeding habitat of an endangered woodpecker species, management of food resources of migratory shorebirds, and management of disturbance near nesting eagles. Each example is comprehensive, in that it includes all the interacting components of adaptive management. In the interest of brevity we omit many of the details required to develop the application fully, and limit ourselves to the information needed to describe the actual implementation of adaptive management.

7.1. Tallapoosa River – R.L. Harris Dam in Alabama

Extensive hydropower development has altered riverine habitats in the southeastern United States, which is a global center of freshwater fish and invertebrate diversity. The Tallapoosa River in east central Alabama is a priority area for aquatic conservation, with a native fish assemblage of 57 species, including 5 species endemic to its river system. Four of the fishes and one mussel are considered to be "at risk" by the Fish and Wildlife Service. Fish and invertebrate populations in one of the highest-quality segments of Tallapoosa habitat were threatened with destruction by daily extreme low flows that dried the river bed, extreme flow variation from floods to trickles, and daily temperature changes from pulsed water releases for hydropower at the utility-owned R.L. Harris Dam.

The Fish and Wildlife Service has been evaluating proposals for relicensing of more than 200 dams in the southeastern United States – including the Harris dam – that are licensed by the Federal Energy Regulatory Commission. Through the Southern Rivers Integrated Science Initiative, the Service has recognized the need for new approaches to evaluate dam relicensing, and new strategies to mitigate the impacts of dam operations on aquatic communities. Rather than the one-time fixed flow regime typical of relicensing prescriptions, adaptive management has been used on the Tallapoosa since 2005 to allow for the adjustment of flow management based on what is learned from system responses. This project is intended to provide a template for incorporating adaptive management and decision support into the relicensing process.

Set-up phase for the Tallapoosa River project

Stakeholders. Project leaders took steps early on to involve stakeholders actively. Neutral, professional third-party facilitators were engaged to help develop and conduct stakeholder fora and workshops, and to gather information from stakeholder polls. Stakeholders created a governance structure, the R.L. Harris Stakeholder Board, for future decision-making. The board includes representatives from the Fish and Wildlife Service and other federal agencies, state and local agencies, conservation groups, river-boating and sport-fishing groups, property-owner groups, and the utility company that owns the dam. Special care was taken to be as inclusive as possible so that all groups and individuals with an investment in the system could have a part in management discussions. Equity in stakeholder representation was sought, in order to avoid skewed voting from over-representation of one entity or viewpoint.

Objectives. Through the facilitated workshops, stakeholders arrived at 10 fundamental objectives that they agreed were representative of all involved parties. Many objectives were in conflict, with potential conflicts centering around maximizing hydropower production and reservoir levels versus maximizing aquatic biodiversity and downstream boating opportunities. The competing stakeholder objectives were incorporated in a decision support framework, with software that created visual representations of the influence diagram of relationships among objectives, as well as visualization of the Bayes belief network and the decision support model. Tradeoffs among all the objectives were considered in developing decision support procedures in which all stakeholders "give a little" to negotiate a starting point for management actions.

Management alternatives. To compromise among user groups, management decisions focused on three main decisions: daily flow rates, seasonal flows for boating, and fish spawning windows (periods of stable flow for spawning). A stream gage in an unregulated stretch of the Tallapoosa provided control data on natural stream flows. Management alternatives were developed for each of the three main decision points, i.e., four alternative daily flow patterns, four alternative spawning window options, and two boating flow options. For example, the primary decision concerned daily flow operations from the dam. The four alternatives to the primary decision were: (*i*) current utility operation, with no change from the twice-daily peak flow pulses of 4 to 6 hours, followed by almost no flow; (*ii*) constant minimum flow to maintain the "natural" target as recorded by the stream gage, plus necessary power generation flows; (*iii*) constant flow to maintain the "natural" target, but never falling below 300 cubic feet per second, plus necessary power generation flows; (*iv*) twice-daily flow pulses to maintain at least 75 percent of the "natural" target (an option proposed by the utility company).

Models. Hypothesized relations between flow features and system responses were modeled by means of a probabilistic Bayes' network. Modeling incorporated four alternative primary flow regimes based on different a priori hypotheses about how fishes and habitat would respond to specific flow conditions. Modeling also included four alternative options for spawning windows – periods of stable flow that allow fish to spawn and juveniles to develop successfully – that expressed different hypotheses about how recruitment of juvenile fish of different species would respond to seasonal spawning windows in spring and summer. Optimization was used to determine the management decision that maximized stakeholder values, which included improving fish habitat and recruitment of juveniles, improving downstream boating during peak season, and maintaining sufficient flow levels for power generation.

Monitoring protocols. Uncertainty about functional relations among flow parameters (e.g., frequency, duration, magnitude) and fish populations needs to be resolved, especially the relations between periods of stable flow and recruitment of young fishes. Protocols were developed for fish sampling as well as the measurement of water flows (e.g., river stage, water column velocity, and substratum type at sampling sites). Data collection was designed to evaluate effects of various flow regimes on occupancy, availability, and persistence of the shallow-slow and shallow-fast habitats needed by various species for spring and summer spawning and survival of young of the year.

Iterative phase for the Tallapoosa River project

Decision making. Decision making incorporated the 10 fundamental objectives that were developed by stakeholders, plus the three main decisions (daily flow pattern, stable flows for fish spawning, and flows for boating). Stakeholders negotiated the starting point for management actions – an initial flow prescription that consisted of (*i*) pulsed flows to increase base flow from the dam, thus mimicking natural hydrology in an unregulated reach of the Tallapoosa; (*ii*) periods of stable flows for fish spawning in both spring and summer; and (*iii*) suitable flows for downstream boating in October.

Post-decision monitoring. Faunal response to management is monitored by collecting numerous fish samples from sites below the dam and in nearby unregulated river reaches. Fish occupancy, extinction, and colonization probabilities are estimated at least twice a year at multiple, randomly selected sampling sites, with pre-positioned area electrofishers (electrodes powered by generators) to stun fish so they can be netted and identified, counted, and measured. Population parameters are being modeled as a function of habitat variables, site location (regulated or unregulated), and attributes related to water availability in the basin and management at the dam. River hydrology data are measured by U.S. Geological Survey flow gages. Stakeholders are involved in aspects of planning and execution of the monitoring plan.

Assessment. Monitoring data collected since 2005 are being used to modify biological hypotheses. Data on flows, habitat characteristics, and fish populations are being analyzed for comparison with predicted responses of fish and habitats to management actions. The decision model was based on hypothesized relations between flow features and fish population responses: depleted low flows, flow instability, and thermal-regime alteration were the main factors hypothesized to affect fishes. Ten explicitly stated uncertainty nodes (e.g., reservoir inflow, lake levels, shallow-fast habitat, slow-cover habitat, degree days, small fish abundance, bass recruitment, redbreast sunfish spawning success) are parameters linked directly to fundamental objectives of stakeholders and hypotheses related to system function. The new information about actual system states will reduce uncertainty about the relationships between flow and system responses.

Learning and feedback. The models are used to predict outcomes of future flow manipulations, which then are compared with actual flows to facilitate learning. Data collected in post-decision monitoring are used in updating the probabilities that represent uncertainty about fish distributions, hydrological flows, and recreation capacity. As uncertainties about the relationships between flow and system responses are reduced, managers and stakeholders will be able to adjust the flow regime as needed to meet management objectives and ensure conservation of at-risk species.

Institutional learning. The original design for monitoring has been adjusted to account for detectability of organisms through the use of occupancy sampling and estimation. An upcoming review of the decision-making process will consider possible changes in other elements of the adaptive management apparatus, including objectives and management alternatives. For example, modification of the underlying biological hypotheses may lead to revision of the models in which they are embedded. If all objectives are attained, future flow adjustments may become necessary to mitigate the effects of other watershed changes that affect flow regimes. Such changes could include drought, land-use changes that affect runoff, or climate change.

7.2. Red knots and horseshoe crabs in Delaware Bay

The sandy beaches of Delaware Bay in Delaware and New Jersey are globally important as spawning grounds for Atlantic horseshoe crabs and as stopover habitat for long-distance migratory shorebirds such as the red knot. Each year the birds stop in Delaware Bay in May to rest and replenish their energy reserves during migration from wintering grounds in temperate and tropical regions to breeding grounds in the Arctic. In the bay, they feed on the seasonally superabundant horseshoe crab eggs deposited on the beaches by millions of crabs that spawn during the lunar tides each spring. Throughout the 1990s a growing and unregulated harvest of horseshoe crabs, for use as bait in eel and whelk fisheries, led to a decline in spawning crabs.

In the late 1990s and early 2000s, monitoring data began to show major declines in red knot abundance. Shorebird scientists and advocacy groups identified horseshoe crab fishing as the root cause of the red knot

decline, and claimed that reduced horseshoe crab egg abundance resulted in decreased survival and reproductive success of migrating birds. Other scientists and horseshoe crab fishermen's groups argued that red knots are not solely reliant on horseshoe crab eggs for food, and that some other environmental factor must be responsible for red knot declines. Conservationists called for a complete cessation of horseshoe crab fishing in the Delaware Bay, while others called for more moderate regulations in order to protect the horseshoe crab fishery. Highly variable data, which could be interpreted to support either side in this ongoing argument, resulted in substantial scientific and decision-making uncertainty. Adaptive management was initiated on this contentious issue, with a goal of identifying a sustainable horseshoe crab harvest strategy that protects red knots and enables learning about how the system functions.

Set-up phase for the red knot and horseshoe crab project

Stakeholders. The horseshoe crab harvest and red knot conservation problem involves numerous stakeholders. The crabs are commercially harvested for bait in eel and whelk fisheries, and are vital to the biomedical industry that uses their unique copper-based blood for medical testing. The red knot is a candidate species for listing under the federal Endangered Species Act and is listed as endangered or as a species of conservation concern in several states. The adaptive management effort has engaged the Atlantic States Marine Fisheries Commission; the Fish and Wildlife Service; the New Jersey, Delaware, Maryland, and Virginia state fisheries and wildlife agencies; the New Jersey Audubon Society; and the Conserve Wildlife Foundation of New Jersey, among other stakeholder organizations. Representatives from the organizations collectively make up a stakeholder committee.

Objectives. Working with the stakeholder organizations, the Delaware Bay adaptive management team (composed of scientists and experts from the various organizations and the U.S. Geological Survey) has developed a unified objective statement that effectively captures the competing resource uses. After extensive discussions, the stakeholders agreed on the statement, "Manage harvest of horseshoe crabs in the Delaware Bay to maximize harvest but also to maintain ecosystem integrity and provide adequate stopover habitat for migrating shorebirds." In order to introduce quantitative, measureable attributes for monitoring purposes, this statement was effectively translated as, "Maximize horseshoe crab harvest as long as red knot population abundance has exceeded some predetermined threshold (45,000 individuals)." The latter objective uses an increase in red knot populations from their current population size of about 20,000 to 45,000 as a surrogate measure for ecosystem integrity and adequate stopover habitat. The red knot abundance metric met the true fundamental objective of several stakeholders, which was to restore red knot populations to some higher level of abundance.

Management alternatives. Because the decision maker and sponsor of the framework development is the Atlantic States Marine Fisheries Commission, management alternatives were restricted exclusively to crab harvest actions. The stakeholder committee considered historic harvests, fishing industry needs, and conservation community concerns in developing a range of harvest actions that reflect those needs and concerns. The possible actions ranged from a full moratorium, to the harvest of as many as half a million crabs, and allowed for differential harvest actions for male and female crabs.

Models. The modeling portion of the Delaware Bay adaptive management project focused on three primary hypotheses about the ecological interactions between the two species. (*i*) The first hypothesis was that horseshoe crab spawning abundance (the number of crabs that crawl up the beach to spawn in the spring) has *dramatic effects* on red knot annual survival and reproductive success. Essentially, birds that do not gain enough weight (i.e., cannot find enough food) during stopover have high mortality and those that do manage to survive the rest of migration that year do not breed. (*ii*) The second hypothesis was that horseshoe crab spawning abundance has a *small effect* on red knot survival and large effect on reproductive success. In the model for this hypothesis, birds that do not gain enough weight during stopover survive the rest of the year with no residual effect, but do not attempt to breed. (*iii*) The third hypothesis was that horseshoe crab populations have *no effect* on red knot population dynamics. This hypothesis assumes that some other environmental issue caused the decline in the red knot population, if in fact the decline truly happened (observed declines may simply be a result of changes in habitat use, or alterations of migratory patterns, or systematic changes in detection rate). These different models predict very different responses by the red knot population to horseshoe crab harvest actions.

Monitoring. Annual decision making requires estimates of the abundance of horseshoe crabs and red knots. The population of adult horseshoe crabs is surveyed annually with a stratified-transect sampling design during the late summer and fall, after the crabs have spawned and returned to deep waters. Offshore trawling is used to dredge up sampled crabs. In past years, red knot abundance was estimated from aerial survey counts conducted in the Delaware Bay during the stopover season. The peak count for a season was considered an index of abundance; however, aerial counts are subject to tremendous counting error and other statistical issues. The adaptive management team recommended abundance estimates based on mark–recapture techniques, which will make use of the mark and recapture effort carried out annually in the bay to assess red knot weight and body condition.

Iterative phase for the red knot and horseshoe crab project

Decision making. In its current form the adaptive management plan calls for annual decisions about harvest regulations. Managers need to assess the abundance of both horseshoe crabs and red knots to determine the best management action, given the state of the two populations and the recognized ecological and environmental uncertainty. Adaptive stochastic dynamic programming techniques provide decision makers with a decision table of optimal harvest actions based on different possible states of the system and the current degree of understanding about the system. The decision recommendations seek to maximize harvest yields over a long time horizon while protecting red knot populations.

Post-decision monitoring. The harvest action is implemented in the summer and fall, after red knot spring migration and crab spawning. The timeline for decision making, assessment, and monitoring is complex, because the action implementation is concurrent with or even later than the assessment monitoring for the next year's decision. The effects of the harvest may not be apparent in assessment and monitoring data for 2 or more years. Following a harvest decision and implementation, managers need to estimate abundance in the same way used to assess the populations before the decision implementation.

Assessment. The three alternative system models corresponding to the three alternative hypotheses make different predictions about red knot abundance in response to horseshoe crab harvest actions. Comparing observed or estimated red knot abundance to the three model predictions allows managers and researchers to determine which of the three hypotheses more effectively represents red knot responses to horseshoe crab harvests.

Learning and feedback. By applying management actions and comparing the observed results with predicted outcomes from the three models, one can gradually learn which model more accurately predicts the system response to horseshoe crab harvest. Confidence will accumulate over time in the model that makes the best predictions about red knot populations. At the beginning of the process, model confidence values are established through expert opinion and stakeholder input. As decision making progresses over time, the model confidence values will be updated using Bayes' rule. The process of sequential assessment and model updating will gradually increase knowledge about the relationship between red knots and horseshoe crabs.

Institutional learning. Every few years, the set-up phase of the adaptive management plan will be revisited. Stakeholder groups will reconvene, objectives will be re-evaluated, and the models (and underlying hypotheses) will be re-evaluated in accordance with what was learned in the iterative phase. As an additional component of the set-up phase, the adaptive management framework for this problem identifies research priorities to address some uncertainties that could not be incorporated into the initial set of three models. Some issues like sex ratio linkage to fertility in horseshoe crab populations, juvenile survival rates of red knots, and first-year survival rates of horseshoe crabs were put aside during the set-up phase, with the intention of revisiting them as new data become available, or as other studies produce results that can be incorporated to improve model predictions. There was disagreement and uncertainty among stakeholders and scientists as to which issues were central to the key ecological relationships; the choice of the particular issues underlying the current set of models represents a compromise on the important hypotheses about ecological relationships. The remaining issues and disagreement were set aside to prevent excessive complexity from inhibiting management decision making. Meanwhile, plans were put in place to address those issues in parallel with iterative decision making, as part of the double-loop learning process.

7.3. Southeastern pine forests and red-cockaded woodpeckers

The endangered red-cockaded woodpecker occurs in mature pine forests of the southeastern United States, most typically in longleaf pine forests of the coastal plain. Patches of old-growth forest provide critical nesting habitat for cooperatively breeding woodpeckers; family groups include helpers at the nest and may be as large as nine birds. Preferred sites are mature, park-like pine stands about 4 hectares in area. The birds select old trees for the excavation of nesting cavities, and family units defend territories around clusters of such trees. Other habitat requirements include over-story and mid-story layers of limited density and an adequate understory, but the old-growth condition is the underlying requirement for successful breeding by woodpecker groups. These habitat conditions were routinely met by the historic disturbances that shaped southeastern pine forests. Red-cockaded woodpeckers also occurred in other pine forest types and in provinces beyond the coastal plain, including loblolly pine forests of the Piedmont.

The recovery plan for the species calls for establishment of primary and secondary populations across different forest types and provinces. One recovery target is the Piedmont National Wildlife Refuge and Chattahoochee–Oconee National Forest complex in central Georgia. These lands came into federal ownership in the 1930s after the collapse of cotton farming in the region. Since then, forests of mixed loblolly pine and hardwoods have become established. The red-cockaded woodpecker population in this forest complex is the largest in the Piedmont physiographic province. Creation and long-term maintenance of old-growth forest is critical for sustaining this population.

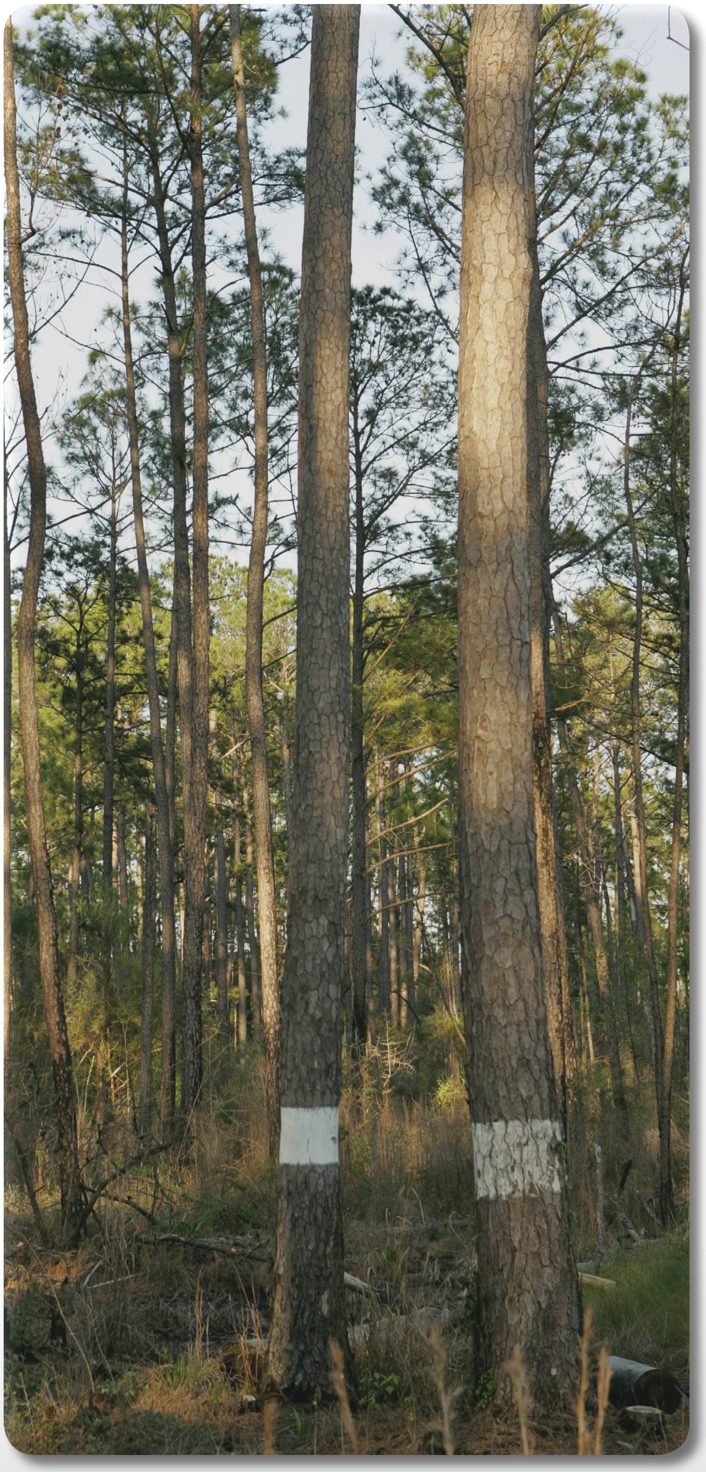
The recovery plan for red-cockaded woodpeckers provides guidance to forest managers on the amount and age-class distribution of annual cutting necessary to sustain old-growth conditions. But these guidelines were derived mostly from experience with longleaf pine forests in the coastal plain, and they do not take into account the current composition of a mixed loblolly pine–hardwood forest or the rate of succession from pine to hardwood in the Piedmont. A faster rate of succession to hardwoods would limit the ability to create old-growth loblolly pine forest, and management strategies would vary depending on this rate. Unfortunately the rate of succession is unknown, so the maximum amount of attainable old-growth forest and the best sequence of harvest actions to reach it are also unknown. At the Piedmont refuge, adaptive management can account for this biological uncertainty in guiding decisions about the harvest strategy to maximize old-growth loblolly pine habitat over the long term.

Set-up phase for the pine forest and woodpecker project

Stakeholder involvement. Final decisions about forest management rest with the refuge manager. However, decisions are made with an awareness of legal mandates as well as the views and demands of different stakeholders. The refuge manager is obligated to meet legal requirements imposed by the Endangered Species Act and to act in accordance with the recovery plan for red-cockaded woodpeckers. Unfortunately, actions under the recovery plan guidelines potentially run counter to management needs of other trust species, which are also obligatory. The manager must be sensitive to needs of the public for consumptive use of the refuge lands and recreational access to them. Finally, the manager must try to provide positive benefit to adjacent landowners and the local community, or at least avoid antagonizing them. Thus, the refuge manager makes each decision in a context of conflicting desires and expectations among stakeholders.

Management objectives. One of the fundamental objectives of management at the Piedmont refuge is to establish a self-sustaining red-cockaded woodpecker population. In the mixed forest settings typified at the refuge, it is clear that achievement of this goal requires active forest management to maintain old-growth forest habitats. Therefore, creation of old-growth habitat was seen as a necessary means to achieve the fundamental objective. Because "sustainability" is a key attribute, an objective for habitat management was defined with a long time horizon. The management objective for the project was the accumulation of the largest sum of annual amounts (hectares) of old-growth pine forest (80 years and older) over a very long time (1,000 years).

Management alternatives. Annual forest harvest and regeneration activities are the means by which managers pursue a future stream of old-growth forest habitat. The refuge's forest managers take these actions for broad age classes of the forest. Pine stands in the refuge are classi-



fied into one of four age groups: P1 (age 0 to 16 years), P2 (age 16 to 40 years), P3 (age 40 to 80 years), and P4 ("old-growth" forest, age 80+ years). Managers contract with private operators to harvest trees in the three older groups (P2 to P4) that produce merchantable timber. Therefore, management alternatives each year are the total amounts of timber harvest from each of the classes P2 through P4. This decision applies to the total annual amounts of harvest, but the specific stands from which timber is cut are determined according to a compartment rotational schedule.

Models. The total forest area of the Piedmont refuge is portrayed at any time as a distribution among five distinct forest types: the four pine classes P1 to P4, and an upland hardwood class, UH. The distribution of these types changes from year to year as a result of transitions among the classes, which are influenced by factors that managers control (harvest) and factors that they do not. Harvest moves portions of classes P2 through P4 into class P1. Growth advances portions of younger pine classes into older classes. Random disturbances such as wind, storms, or insect infestations cause portions of the age classes to transition to P1. Annual forest succession results in transition to type UH by portions of all pine types. Parameters that describe these transitions either exist or can be reasonably inferred, except those for hardwood succession. The limited data that exist provide a wide range of plausible rates of succession. To account for this uncertainty, three models were constructed with different rates of hardwood succession. Given a current forest state (the distribution of Piedmont refuge forest among forest types) and a management action (amount of harvest from each class, P2 through P4), each model generates a distinct prediction of forest state in the next year. The models have different implications about the maximum amount of old-growth pine forest that can be sustained through harvest, as well as the means by which to achieve that outcome.

Monitoring protocols. The annual sampling plan includes basal area, over-story density, stand type, and stand age. These data provide a means of measuring forest composition for decision making and assessment of the predictive quality of the models. However, the annual surveys are conducted on only one of eight subsets of the refuge's 34 management compartments each year. A survey of the entire refuge therefore is accomplished every 8 years. At longer but irregular intervals, a complete forest assessment is available through interpretation of remotely sensed data. To integrate the time step of monitoring (8+ years) fully with the time step of model prediction and decision making, either of two approaches can be used. One is to conduct an annual forest-wide survey for the key variables of interest, perhaps at reduced spatial density and in conjunction with some other type of resource monitoring (e.g., bird counts). Another option is to recast the decision framework in a time step that more closely matches the temporal resolution of the available data. For example, recasting the problem in an 8-year time step would produce an 8-year schedule of actions (but also an 8-year time interval between learning opportunities).

Iterative phase for the pine forest and woodpecker project

Decision making. With knowledge of the current composition of the refuge forest and uncertainty about the rates of hardwood succession, forest managers reach a decision each year about the total amount to cut out of the P2, P3, and P4 pine forest classes to sustain a maximum amount of old-growth forest. Optimal decision analysis with adaptive stochastic dynamic programming accounts for the current forest composition, degree of uncertainty about hardwood succession, and future forest dynamics resulting from a current harvest decision. A critical feature of the decision analysis is that it explicitly includes the possibility of learning to help resolve uncertainty and improve long-term management. In effect, "experimental" actions, which involve some near-term resource sacrifice but have the potential for longer-term resource gain, are to be compared with actions that preserve short-term gain but offer little expectation of learning.

Post-decision monitoring. Refuge biologists conduct a systematic (grid-based) sampling of the forests each year over a subset of the 34 management areas that constitute the refuge. The current scheme of rotational timber surveys results in opportunities for model assessment only every 8 years, whereas changes in forest states are perceptible over much shorter time periods. An alternative that includes annual assessment of refuge-wide forest state (with lower spatial density of sampling points and collection of the most critical variables for decision making) would provide the information for incremental updates of knowledge about forest dynamics before each decision.

Assessment. Each of the three alternative models generates a distinct prediction of the forest state following a harvest decision. Forest monitoring data that are collected before the next action provide a means of assessing how well the models perform. For example, the amount of P4 forest occurring at the next time period is one of the state components predicted by each model. Because the models contain random mechanisms (to mimic random disturbances and other random transitions), each model predicts a distribution of P4 forest amounts rather than a single value. These distributions are compared with the monitoring data characterizing the amount of forest-wide P4.

Learning and feedback. At each time step in the decision-making process, the three models are evaluated with monitoring data and the outcomes are accumulated in model credibility weights. If a model's prediction agrees well with the data, its credibility increases. If a model's prediction agrees poorly, its credibility declines. The updating of weights is accomplished through application of Bayes' rule each year. Because credibility is gained by some models and lost by others, uncertainty about hardwood succession is successively reduced, and the quality of future decision making improves. After the learning and feedback step, the adaptive management cycle is completed when the forest manager uses the new information about model credibility in making decisions.

Institutional learning. A closer integration of the current monitoring program with the decision structure would permit a more informed implementation of an adaptive framework for forest decision making on the Piedmont refuge. At some time after implementation, there may be a need to review and revise elements of the process. For example, the management objective currently has no component that reflects the cost of producing P4 habitat. A cost component could be incorporated, which could include real financial costs of carrying out the harvest actions or the ecological costs borne by other species in the conversion of suitable forest habitat to unsuitable early succession habitat. Another example would be the possibility of learning over time that hardwood succession is so rapid that it makes the creation of any meaningful amount of old-growth habitat an unreasonable prospect. Such a finding could stimulate a search for new management alternatives, such as the installation of artificial cavities in younger stands that are less vulnerable to hardwood succession.

7.4. Golden eagles in Denali National Park

Throughout the Northern Hemisphere, the golden eagle is the pre-eminent diurnal predator of medium-sized birds and mammals in open country. The mountainous regions of Alaska's Denali National Park support the highest nesting density of golden eagles in North America, with abundant snowshoe hares, ptarmigan, and other prey and undisturbed cliffs for nests that are used over decades or even centuries. Nesting eagles are sensitive to human disturbance, and the National Park Service must limit human presence near nest sites in order to maintain Denali's eagle population. During their reproductive cycle of nest repair, egg-laying, and brood rearing, eagles may occupy any of nearly 100 potential nesting sites across the northeastern part of the park between March and September. Denali is also a premier destination for wilderness recreation during the summer months, during which back-country hiking, airplane tours, and other recreational activities may negatively affect the occupancy of potential nesting sites by eagles and therefore reduce overall breeding success. In 2007, National Park Service biologists and managers at Denali began collaboration with U.S. Geological Survey scientists to develop an adaptive management project to manage human disturbance of nesting golden eagles.

Set-up phase for the golden eagle project

Stakeholder involvement. Stakeholders for this project consist of a small group of federal agency managers and scientists. National Park Service managers include the inventory and monitoring coordinator for the Central Alaska Network and the biologist responsible for the annual eagle monitoring program. Collaborators from the U.S. Geological Survey include an Alaska Science Center scientist familiar with the eagles and with adaptive management, and two scientists from Patuxent Wildlife Research Center with expertise in animal monitoring methods and decision analysis. The superintendent of Denali National Park is the ultimate decision maker for any Denali management efforts.

Management objectives. Objectives for national parks usually include conservation of natural areas and ecological systems, as well as facilitation of human enjoyment and use. Park managers are aware that these two basic objectives may be in conflict. The general objectives of Denali's adaptive management project are to maintain eagle numbers at historical levels while permitting recreational use of the Park. The adaptive management working group specified a desired threshold number of golden eagle nesting territories at which successful breeding occurs. The primary management action for Denali managers is the closure of potential nesting sites to recreational hikers. Thus, the specific objective was to maximize the number of potential nesting sites that are open to hikers, subject to the constraint that the projected number of successful breeding sites the next season exceeds the established threshold.

Management alternatives. Adaptive management focuses on hiker disturbance. Of all potential nest sites, only those near the main road through Denali were thought to be exposed to hiker disturbance. The potential management actions thus involved closure of as many as all of these sites, or closure of as few as none. The specific management decision was how many of these sites to close to hiking next season, on the basis of information obtained about eagle occupancy and reproductive success during the current breeding season.

Models. The previous monitoring efforts provided a useful data set for an analysis in which occupancy estimation models accounting for detectability were fitted to historical monitoring data. These analyses suggested that the proportion of eagle nest sites at which successful reproduction occurs is affected by both human disturbance and snowshoe hare (prey) abundance. These relationships were incorporated into one model of eagle occupancy and reproductive success. However, the evidence in favor of this model was not overwhelming, and there was substantial uncertainty about factors influencing eagle occupancy and reproductive success. This uncertainty was expressed by the development of two additional models. One depicted virtually no effect of disturbance on eagle reproductive success, whereas the other reflected a strong effect. The data-based model was intermediate between these extreme models in terms of human disturbance effects. Reduction of this uncertainty (i.e., settling on a single most plausible model) is expected to lead to improved management.

Monitoring protocols. The replicated surveys of all potential nesting sites each breeding season provide the information needed to estimate the proportion of sites occupied by eagles and the proportion of sites at which successful reproduction occurs. Data on hare abundance collected during these surveys provide an index of hare abundance. These quantities then become the predictors of subsequent eagle occupancy and reproductive success in all three management models.

Iterative phase for the golden eagle project

Decision making. Objectives, actions, models, and current understanding were used with dynamic optimization to produce optimal decision matrices. To use these matrices the manager simply needs to specify the current condition of the system (eagle occupancy and reproductive success, hare abundance) on the basis of the most recent monitoring results. An optimal management action is then identified for each of the possible estimates of eagle and hare "state."

Post-decision monitoring. The current monitoring program will continue throughout the adaptive management project. All potential nest sites are visited by helicopter and on foot in the spring and summer. For inference about occupancy, sites are visited on multiple occasions until eagles are detected, with a maximum of three visits per site. Each site at which eagles are detected is visited again in July to assess reproductive success. Data (fecal pellet counts) for a hare abundance index are collected at each site as well.

Assessment. Each of the three alternative models generates a distinct prediction about the proportion of sites that are expected to be occupied by eagles the next season and the fraction of those at which reproduction is successful. The predictions are not single values but distributions of values, reflecting the uncertainty of any predictive process. These predictions are then used in the subsequent learning phase.

Learning and feedback. Comparisons of the model-based predictions with the monitoring estimates of eagle occupancy and reproductive success provide information about the predictive abilities of each model, with changes in the measures based on a comparison with monitoring estimates. Specifically, the adaptive management process includes measures of relative credibility for each model. The changes in credibility measures effectively modify the influence of each model in the decision process so that models that are better predictors gain more influence. Changes in these measures provide a quantitative measure of learning.

Institutional learning. A monitoring program for golden eagles has been ongoing for over two decades, and the current management program provides an explicit process for using monitoring information directly to make management decisions. After some experience with this program, a logical next step would be to consider other potential sources of disturbance such as airplane flights for tourists. Future management actions in this case would entail specification of flight paths that limit potential disturbance to eagle nest sites. Another extension might be to incorporate annual estimates of the annual numbers of visitors at the sites.

Denali National Park and Preserve, Alaska